Malapert Mountain: A Suggested Site for a Lunar Outpost

Paul D. Lowman Jr.
Goddard Space Flight Center (Code 698)
Greenbelt, MD 20771
Paul.D.Lowman@nasa.gov

Abstract **18 May 2006**

This paper reviews the characteristics of the lunarsouth pole crater Shackleton and Malapert Mountain, due north of Shackleton at 85 deg. latitude. Early photographs of Shackleton from the Clementine mission indicated that the rim of Shackleton is in continual sunlight, making it a prime candidate for a robotic landing or eventual lunar outpost. However, Lunar Orbiter IV photos show that much of Shackleton's rim is partly or wholly shaded at times during the year. The north side and top of Malapert Mountain in contrast are illuminated about 90% of the year. Furthermore, Malapert Mountain is mature highland terrain, probably with a thick workable regolith and a high content of implanted solar wind volatiles such as hydrogen and helium-3. The south side is permanently shaded, and within the area of low neutron flux (i.e., high hydrogen content), found by the Lunar Prospector mission. The top of Malapert Mountain offers a relatively smooth broad area, roughly 50 km in E-W dimensions, whereas the rim of Shackleton, with a total diameter of only 19 km, is a narrow and probably rough landing site. It is recommended that Malapert Mountain be given systematic study before any decision is made on a south polar landing site, since it appears to offer a much safer landing site and other major advantages.

Introduction

The 2005 NASA Exploration Systems Architecture Study (ESAS) includes a south polar site as part of a lunar design reference mission (DRM). The rim of the 19 km Shackleton Crater has been recommended as a site for initial robotic landings, and possibly for a permanent outpost (Bussey and Spudis, 2004). In addition to its dynamic accessibility, e.g. anytime return, using a lunar orbital rendezvous (LOR) mode, most of the rim of Shackleton appears (Bussey et al., 2003) to be in continual sunlight, at least for the three months of the Clementine mission. It therefore offers in principle uninterrupted solar energy and access to adjacent shaded regions with hydrogen concentrations. However, a more extensive examination of the south polar regions has been made using Lunar Orbiter IV photographs, which covered the area several times (Table 1), and it appears that the Shackleton illumination may be less favorable than previously thought.

The purpose of this paper is to suggest an alternate location, on Malapert Mountain, for initial robotic landings and for an eventual lunar outpost, leading up to "a permanent human presence on the Moon" as described in the ESAS (p.71), and the 2006 NASA Strategic Plan. This site has been recommended by Schrunk et al. (1999) and Sharpe et al. (2003) primarily on the basis of illumination. However, there are additional factors that support this recommendation, to be discussed.

To show south pole geography and lighting, a series of illustrations has been compiled. The first (Fig.1), a 3 month 750 nm mosaic from Clementine (Shoemaker et al., 1994), provides a good introduction to the region. A gridded version (Fig.2), from Bussey and Spudis (2004) is accompanied by a shaded relief map (Fig.3) A 12.6 cm radar mosaic (Fig.4) produced by the Arecibo system (Stacy et al., 1997)shows the topography as illuminated from Earth. An interesting aspect of this mosaic is that it demonstrates the visibility of large parts of the shaded polar areas by earthlight for at least part of the month (Head and Lowman, in preparation).

The second month's polar coverage from ClementineSpudis and Busse, 2003) is shown in Fig. 5, a mosaic of about 650 images up to 80 deg. S, illustrating the illumination of Shackleton crater. The crater rim over this period is sunlit completely. However, this is a small fraction of the lunar year, and as earlier discussed by Spudis et al. (1995), the polar regions do have seasons, since the Moon's axis is inclined 1.6 deg. from the normal to the plane of the ecliptic. Zuber and Garrick-Bethell (2005) have shown that because of the 3 month duration of the Clementine coverage, we do not yet have enough topographic data to ensure continual illumination in south polar areas including Shackleton. Stacy et al. (1997) had made the same point, citing the 18.6 year precessional period of the Moon's rotational axis.

The Lunar Orbiter pictures (Table 1), selected from the Digital Lunar Orbiter Photographic Atlas of the Moon (Lunar and Planetary Institute,2005), show that the illumination of the Shackleton rim has been exaggerated, and that it may be partly or completely shaded. The large crater Amundsen is a convenient landmark in the following pictures, starting with Fig. 6, a high altitude medium resolution view. Most of Shackleton's rim is indeed illuminated at one time, as confirmed by Fig. 7, a high resolution photograph taken at the same time. Other photos, not reproduced here (see Table 1), also show much of the rim. However, on one photo (Fig. 8), so little of the rim is shown that the circular shape is not visible; note the decreasing visibility of Amundsen in this view. In Fig. 9 and Fig. 10, only a small fraction of the Shackleton rim is illuminated, and it is not always the same fraction. It is clear that the south pole mosaic of Fig. 5 does not cover a long enough time to be truly representative of the lighting conditions on the rim of Shackleton.

This examination has been a preliminary reconnaissance, and should be followed up by a detailed photogrammetric study. However, even this cursory examination of Lunar Orbiter photos confirms the problem, and it is clear that selection of a Shackleton site for an outpost would be unwise in terms of present knowledge.

Turning to Malapert Mountain (MM henceforth), we see a much more favorable situation in regard to long-term sunlight. This "mountain" is the south rim of an old, highly eroded highland crater, Malapert (Figs.3and 4). The Clementine and Lunar Orbiter photos show that the north face of MM is almost continually illuminated, while

Malapert Mountain: A Suggested Site for a Lunar Outpost

Paul D. Lowman Jr.
Goddard Space Flight Center (Code 698)
Greenbelt, MD 20771
Paul.D.Lowman@nasa.gov

Abstract **18 May 2006**

This paper reviews the characteristics of the lunar south pole crater Shackleton and Malapert Mountain, due north of Shackleton at 85 deg. latitude. Early photographs of Shackleton from the Clementine mission indicated that the rim of Shackleton is in continual sunlight, making it a prime candidate for a robotic landing or eventual lunar outpost. However, Lunar Orbiter IV photos show that much of Shackleton's rim is partly or wholly shaded at times during the year. The north side and top of Malapert Mountain in contrast are illuminated about 90% of the year. Furthermore, Malapert Mountain is mature highland terrain, probably with a thick workable regolith and a high content of implanted solar wind volatiles such as hydrogen and helium-3. The south side is permanently shaded, and within the area of low neutron flux (i.e., high hydrogen content), found by the Lunar Prospector mission. The top of Malapert Mountain offers a relatively smooth broad area, roughly 50 km in E-W dimensions, whereas the rim of Shackleton, with a total diameter of only 19 km, is a narrow and probably rough landing site. It is recommended that Malapert Mountain be given systematic study before any decision is made on a south polar landing site, since it appears to offer a much safer landing site and other major advantages.

Introduction

The 2005 NASA Exploration Systems Architecture Study (ESAS) includes a south polar site as part of a lunar design reference mission (DRM). The rim of the 19 km Shackleton Crater has been recommended as a site for initial robotic landings, and possibly for a permanent outpost (Bussey and Spudis, 2004). In addition to its dynamic accessibility, e.g. anytime return, using a lunar orbital rendezvous (LOR) mode, most of the rim of Shackleton appears (Bussey et al., 2003) to be in continual sunlight, at least for the three months of the Clementine mission. It therefore offers in principle uninterrupted solar energy and access to adjacent shaded regions with hydrogen concentrations. However, a more extensive examination of the south polar regions has been made using Lunar Orbiter IV photographs, which covered the area several times (Table 1), and it appears that the Shackleton illumination may be less favorable than previously thought.

The purpose of this paper is to suggest an alternate location, on Malapert Mountain, for initial robotic landings and for an eventual lunar outpost, leading up to "a permanent human presence on the Moon" as described in the ESAS (p.71), and the 2006 NASA Strategic Plan. This site has been recommended by Schrunk et al. (1999) and Sharpe et al. (2003) primarily on the basis of illumination. However, there are additional factors that support this recommendation, to be discussed.

To show south pole geography and lighting, a series of illustrations has been compiled. The first (Fig.1), a 3 month 750 nm mosaic from Clementine (Shoemaker et al., 1994), provides a good introduction to the region. A gridded version (Fig.2), from Bussey and Spudis (2004) is accompanied by a shaded relief map (Fig.3) A 12.6 cm radar mosaic (Fig.4) produced by the Arecibo system (Stacy et al., 1997)shows the topography as illuminated from Earth. An interesting aspect of this mosaic is that it demonstrates the visibility of large parts of the shaded polar areas by earthlight for at least part of the month (Head and Lowman, in preparation).

The second month's polar coverage from ClementineSpudis and Busse, 2003) is shown in Fig. 5, a mosaic of about 650 images up to 80 deg. S, illustrating the illumination of Shackleton crater. The crater rim over this period is sunlit completely. However, this is a small fraction of the lunar year, and as earlier discussed by Spudis et al. (1995), the polar regions do have seasons, since the Moon's axis is inclined 1.6 deg. from the normal to the plane of the ecliptic. Zuber and Garrick-Bethell (2005) have shown that because of the 3 month duration of the Clementine coverage, we do not yet have enough topographic data to ensure continual illumination in south polar areas including Shackleton. Stacy et al. (1997) had made the same point, citing the 18.6 year precessional period of the Moon's rotational axis.

The Lunar Orbiter pictures (Table 1), selected from the Digital Lunar Orbiter Photographic Atlas of the Moon (Lunar and Planetary Institute,2005), show that the illumination of the Shackleton rim has been exaggerated, and that it may be partly or completely shaded. The large crater Amundsen is a convenient landmark in the following pictures, starting with Fig. 6, a high altitude medium resolution view. Most of Shackleton's rim is indeed illuminated at one time, as confirmed by Fig. 7, a high resolution photograph taken at the same time. Other photos, not reproduced here (see Table 1), also show much of the rim. However, on one photo (Fig. 8), so little of the rim is shown that the circular shape is not visible; note the decreasing visibility of Amundsen in this view. In Fig. 9 and Fig. 10, only a small fraction of the Shackleton rim is illuminated, and it is not always the same fraction. It is clear that the south pole mosaic of Fig. 5 does not cover a long enough time to be truly representative of the lighting conditions on the rim of Shackleton.

This examination has been a preliminary reconnaissance, and should be followed up by a detailed photogrammetric study. However, even this cursory examination of Lunar Orbiter photos confirms the problem, and it is clear that selection of a Shackleton site for an outpost would be unwise in terms of present knowledge.

Turning to Malapert Mountain (MM henceforth), we see a much more favorable situation in regard to long-term sunlight. This "mountain" is the south rim of an old, highly eroded highland crater, Malapert (Figs.3and 4). The Clementine and Lunar Orbiter photos show that the north face of MM is almost continually illuminated, while the south face is continually shaded. Sharpe et al. (2003) estimated that MM receives 89% full and 4% partial sunlight during the lunar year, and recommended MM as an outpost site for this reason, and for the relatively stable temperature. They show an enlarged view of MM (Fig.11) illustrating these points. However, the advantage of a MM site, beyond illumination ,are substantial, and will be summarized here.

1. **Mission Safety**

Shackleton and Malapert Mountain are both approachable, using the LOR mode, by a polar LOI track from the north. However, MM is clearly a much easier landing site because of its area (Fig.11) , roughly 50 km E-W, much greater than the rim of Shackleton (19 km total crater diameter). MM is shown by Arecibo radar imagery to be in continual microwave visibility of Earth, permitting continual tracking and communication. Both sites are at zero longitude, and a polar LOI trajectory could avoid any major mascons, simplifying tracking. Shackleton may be more difficult to approach during the final powered descent because of its higher latitude. Rough topography between Shackleton and Earth may cause intermittent loss of signal; MM itself has a large radar shadow along the zero degree meridian. Topographic data from the LRO mission may mitigate this problem, but at this point MM appears much safer as a landing site from tracking and communications considerations alone, in addition to the greater area of the MM summit.

2. **Landing site topography**

The LRO mission will produce data from the Lunar Orbiter Laser Altimeter (LOLA) (Smith et al., 2003) on global and polar topography, such as surface slopes and roughness. However, even before that, it appears that MM is much more favorable than the rim of Shackleton.

Shackleton appears, from radar and Clementine imagery, to be a relatively young crater, probably Eratosthenian in age since it does not on available imagery (low sun angle) show rays. Its topography except for the rim is not visible on present imagery, although earthlight probably illuminates its outer rim at zero phase angle as previously mentioned. Crater topography is size-sensitive, but a reasonable comparison to Shackleton (19 km wide) can be made with the 27 km crater Euler, located on Mare Imbrium (Fig. 12). This Apollo photograph shows, first, the narrowness of the crater rim. It also shows the steep and rough crater walls. If the interior of Shackleton (not only shaded but radar-invisible from Earth) is like Euler, it would be challenging for a robotic rover sent to investigate the nature of hydrogen deposits in shaded polar areas. The surroundings of Shackleton, as a young crater, may resemble the outer flanks of Tycho (Fig. 13), with many rocks and a thin regolith.

The meter-scale topography of MM should be much more favorable to landing and surface traverses, and eventually to establishment of a lunar outpost. It is highland terrain, shown as "pre-Nectarian undivided" by Wilhelms (1987), and correspondingly mature. Comparable terrain, though younger, was investigated on the Apollo 15, 16, and

17 missions. The most important aspect of the regolith in such areas is that it is similar in most areas of the Moon except for obvious young craters. This is demonstrated by data from the Surveyor missions (Figs. 14 and 15). The small crater populations and the surface particle size distributions on several Surveyor mare sites were found to be similar, implying (Morris and Shoemaker, 1969) that the local regolith was a steady-state one, formed by long-term impact gardening. As applied to the maria, this means that the mare regolith is similar everywhere with the exception of young crater flanks.

This interpretation applies to the highlandregolith even more strongly, the highlands being much older than the maria. The grain-size distribution curves for Apollo 16 and other sites demonstrate the similarity and maturity of highland regolith (Fig. 17). The summit and presumably flanks of MM can therefore be expected to resemble the highland areas investigated by two Apollo missions: the Apennine front and the Taurus-Littrow massifs. Given the even greater age of the MM site, we can expect a thicker regolith (not including the supposed "megaregolith"). In simplistic terms, landing at Shackleton would be comparable to landing on the bedrock rim of Barringer Crater, whereas landing on Malapert Mountain would be like landing on a sandy beach, though possibly a rock-strewn one.

The flanks and rim ofShackleton, on the other hand, to the extent that this crater resembles Tycho, would be significantly different. As discussed by Shoemaker and Morris (1969) and shown in Figs.16, there are more coarse (ca one meter) fragments per unit area on the Tycho flank than on mare sites studied by Surveyors I and III, though the size-frequency distribution of smaller particles is similar. The presumably reflects the younger age of Tycho. An important finding from Surveyor VII, brought out by Shoemaker and Morris, is that the regolith at the Surveyor VII site is thinner than at mare sites, as indeed shown by the Surveyor VII photographs.

These findings have major significance for a choice of site for robotic landings and outpost establishment. They imply that the summit of Malapert Mountain, apparently cut by only one visible crater (Fig.11), is a fairly level area, with relatively few large rocks, and a thick, workable regolith. The mechanical advantages of such a terrain are obvious. However, a mature highland regolith should offer in situ resource utilization advantages over the thinner one predicted at Shackleton.

First, a thickregolith can be more easily excavated and used for shelters or resource extraction. Furthermore, because of its great age and long term exposure to the solar wind, the MM regolith can be expected to have a higher proportion of implanted volatiles than that at Shackleton. Crider and Vondrak (2000) show that the solar wind may be an alternate, or additional, source of hydrogen in the polar regions. A detailed discussion of implantation factors has been presented by Schmitt (2006), who points out that hydrogen concentration in the regolith increases toward the poles. One of the first objectives of a robotic landing on MM should be either sample return or in situ analysis of the solar volatile content of the regolith, including helium 3, a potentially valuable export to Earth (Schmitt, 2006).

3. Access to permanently-shaded areas

Investigation and evaluation of the polar hydrogen deposits is a major objective of early lunar missions. The rim of Shackleton, and its interior, are indisputably of great interest in this regard. However, MM is just as well situated. The epithermal neutron maps of Feldman et al (1998) show that the south flank of MM, permanently shaded, is in the area of lowest epithermal neutron flux, i.e, highest hydrogen concentration. A rover could therefore drive south from the MM crest and immediately encounter hydrogen-bearing terrain. Furthermore, because of the greater physiographic age of MM, its south flank would almost certainly have gentle slopes and few craters, comparable to the Apennine Front. In contrast, the inner rim of Shackleton, as previously discussed, would probably be much less trafficable.

MM is also close to the low neutron area south ofCabeus (Fig.3), also permanently-shaded. A rover could drive down the west flank of MM in sunlight to reach the dark area.

4. Access to lower latitude areas (farther north)

Establishment of a permanent settlement at the south pole should eventually lead to long-range surface exploration by telerobotic or manned surface vehicles, presumably solar-powered. Shackleton crater is surrounded by permanently shaded terrain, in which solar energy can not be obtained directly. A wired AC power grid (Schrunk et al., 1999) or long power cables can eventually be established, but this would obviously add to Life Cycle Costs. The summit of MM, in contrast, is not so surrounded,but as previously discussed gives surface access to the northwest to areas with at least periodic sunlight. Solar-powered vehicles could thus sortie from a MM outpost using only PV power, though limited by day-night cycling.

5.Suitability for human settlement

A permanent lunar outpost at the south pole would be far more achievable on the summit of Malapert Mountain than on (or in) Shackleton crater, for reasons previously touched upon. Most obviously, there is far more usable area on MM than on the rim of Shackleton. There may be more illuminated time on MM, as estimated by Sharpe et al. , but in any event there would be much more area for emplacement of large PV arrays. The thicker and more mature regolith, previously discussed, would obviously be a major advantage over the Shackleton rim. Psychological factors would be beyond the scope of this report, but having the Earth in continuous view, hanging over the northern horizon, would be assured from the MM summit. Continual sunlight on large areas would also help outpost morale. The thermal environment would be much more benign, without the 150 degree variability of low lunar latitudes over a month.

Summary

Given the objectives and constraints for a return to the Moon as presented in the 2006 ESAS, Malapert Mountain appears superior to the rim of Shackleton Crater as a robotic and eventually a manned landing site. Malapert Mountain is clearly better than Shackleton as a site for a permanent lunar outpost, another ESAS objective. It is therefore recommended that intensive study of Malapert Mountain be carried out before mission plans are finalized. The results presented here are preliminary and qualitative, and should be followed by a detailed photogrammetric survey pending the LRO mission.

References

Bussey, B., and Spudis, P.D., 2004. The Clementine Atlas of the Moon, Cambridge University Press, New York, 316 p.

Bussey, D.B.J., Lucey, P.G., Steutel, D., Robinson, M.S.,Spudis, P.D., and Edwards, K.D.,(2003) Permanent shadow in simple craters near the lunar poles, Geophysical Research Letters, 30(6), 1278 –1280.

Campbell, B.A.,Campbell, D.B., Chandler, J.F., Hine, A.A., Nolan, M.C., and Perillat, P.J. (2003), Radar imaging of the lunar poles, Nature, 426, 137-138.

Crider, D.H, and Vondrak, R.R., 2000, The solar wind as a possible source of lunar polar hydrogen deposits, Journal of Geophysical Research, 105, E11, 26773-26782.

Feldman, W.C., et al., 1998, Major compositional units of the Moon:Lunar prospector thermal and fast neutrons, Science, 281,1489-1493.

Kovach, R.L., Watkins, J.S., and Talwani, P., 1972, Active seismic experiment, in Apollo 16 Preliminary Science Report, NASA SP-315, P. 10-1 to 10-15.

Lowman, P.D.,Jr., 1969, Lunar Panorama, WELTFLUGBILD Reinhold A. Mueller, Zurich, 105 p.

Lunar and Planetary Institute, 2005, Clementine Explores the Moon, LPI Contribution No. 929 (on Internet).

Mitchell, J.K., and 5 others, 1972, Soil-mechanics experiment, in Apollo 15 Preliminary Science Report, NASA SP-289, p. 7-1 to 7-28.

Morris, E.D., and Shoemaker, E.M., ,1969, Craters, in Surveyor Program Results, NASA SP-184, National Aeronautics and Space Administration, p. 63-68.

Nozette, S., and 33 others (1994), The Clementine mission to the Moon: Scientific overview, Science, 266,1835-1839.

Schmitt, H.H., 2006, Return to the Moon, Copernicus Books, New York,335 p.

Schrunk, D., Sharpe, B., Cooper, B., and Thangavelu, M., 1999, The Moon: Resources, Future Development, and Colonization, Wiley, New York, 432 p.

Sharpe, B.L., Schrunk, D.G., and Thangvalu, M., 2003, Lunar reference mission: Malapert station, presented at the 2003 International Lunar Conference, Waikoloa, HI, Nov. 16-22.

Shoemaker, E.M., and Morris, E.C., 1969, Size-frequency distribution of fragmental debris, in Surveyor Program Results, NASA SP-184, National Aeronautics and Space Administration, p. 82-96.

Shoemaker, E.M., Robinson, M.S., and Eliason, E.M., 1994, The south pole region of the Moon as seen by Clementine, Science 266, 1851-1854.

Smith, D.E., 2004, LOLA: Lunar Orbiter Laser Altimeter, Proposal.

Spudis, P.D., Stockstill, K.R., Ockels, W.J., and Kruijft, M., (1995), Physical environment of the lunar south pole from Clementine data: Implications for future exploration of the Moon, Lunar and Planetary Science Conference XXVI, 1339-1340

Stacy, N.J.S., Campbell, D.B., and Ford, P.G.,(1997) Arecibo radar mapping of the lunar poles: A search for ice deposits, Science, 276, 1527-1530.

Wilhelms, D.E., 1987, The Geologic History of the Moon, U.S. Geological Survey Professional Paper 1348, 302 p.

Zuber, M.T., and Garrick-Bethell, I., 2005, What do we need to know to land on the Moon again?, Science, 310,983-985.

Figure Captions

1. **Clementine mosaic of lunar south polar regions (Shoemaker et al, 1994**
2. **Gridded mosaic of Fig. 1; latitude interval 2 degree, longitude 15 degrees.**
3. **Shaded relief map of area in Fig. 2 (From Busse and Spudis, 2004)**
4. **Arecibo radar mosaic of south pole (from Stacy et al., 1997)**
5. **South pole mosaic, 650 images, second month of coverage.**
6. **Lunar Orbiter IV-118-M high altitude photo of southern regions of Moon.**

7. Lunar Orbiter IV-118-H1 photo of south pole region.

8. Lunar Orbiter IV-154-H1 photo of south pole region.

9. Lunar Orbiter IV-H-166-H1 photo of south pole region. Crater rim north (right) of Shackleton rim is part of Shoemaker.

10. Lunar Orbiter IV-179-H1 photo of south pole region.

11. Malapert Mountain, from Sharpe et al., 2003. North(toward earth) at top.

12. Euler crater, Apollo 17 metric camera photo, AS 17-2730, National Space Science Data Center.

13. Surveyor VII mosaic, NASA 68-H-40; view to northeast.(from Lowman,1969)

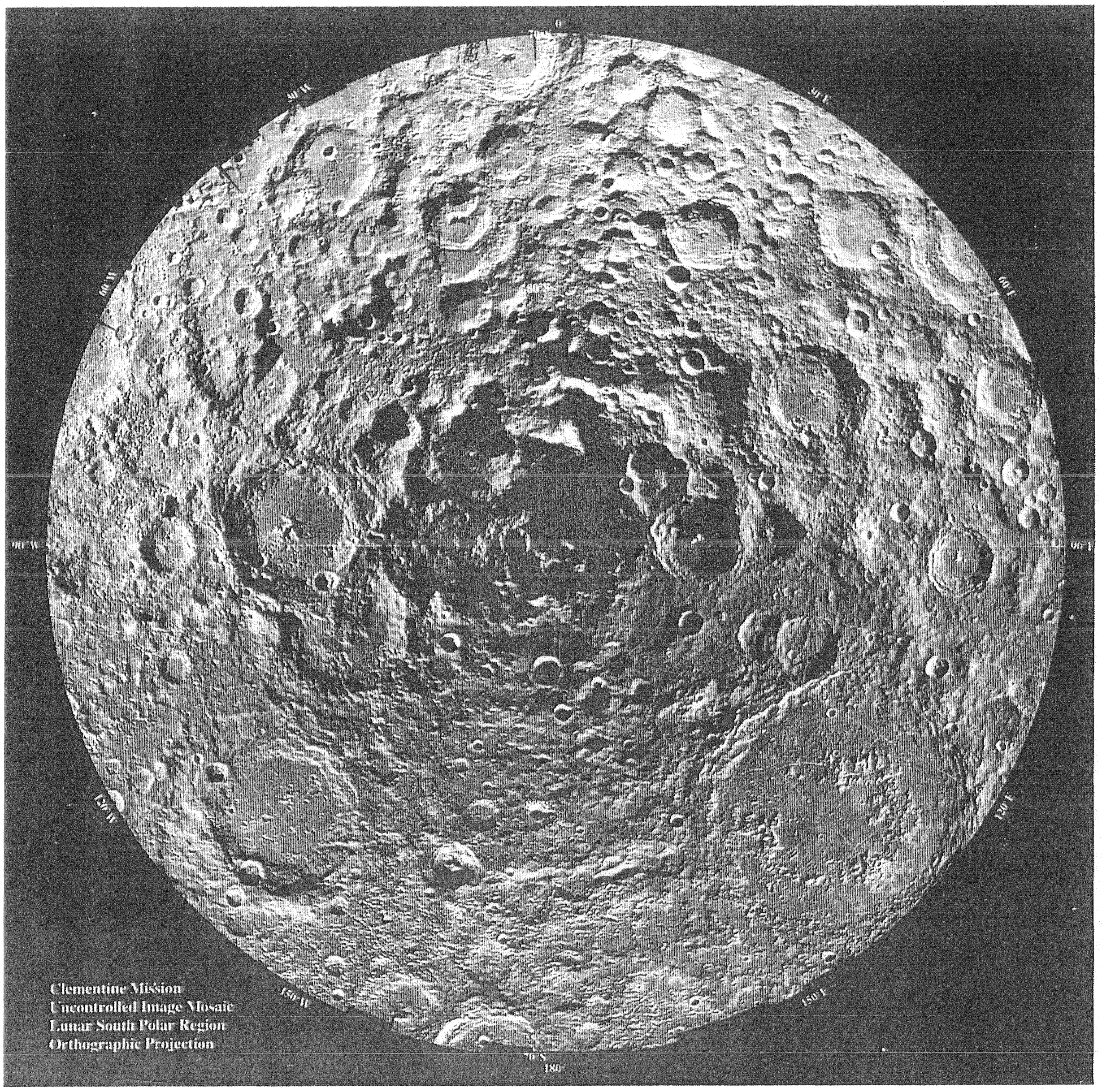
14. Small crater populations, Surveyor I and VI sites (Morris and Shoemaker, 1969)

15. Surface particle size distribution, from Surveyor I and III (Morris and Shoemaker, 1969)

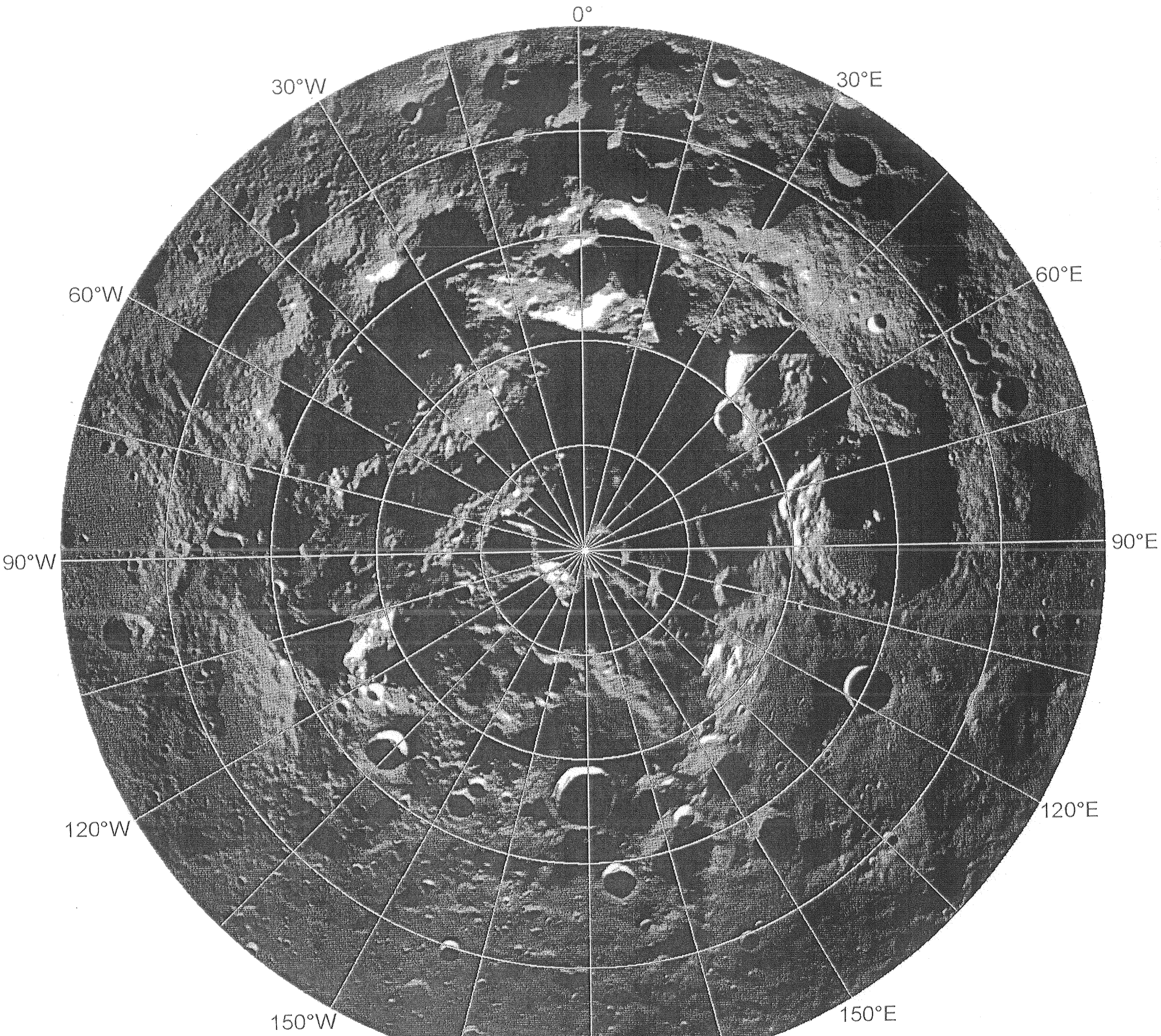
16. Surface fragment size distribution, Surveyor VII and others (Shoemaker and Morris, 1969)

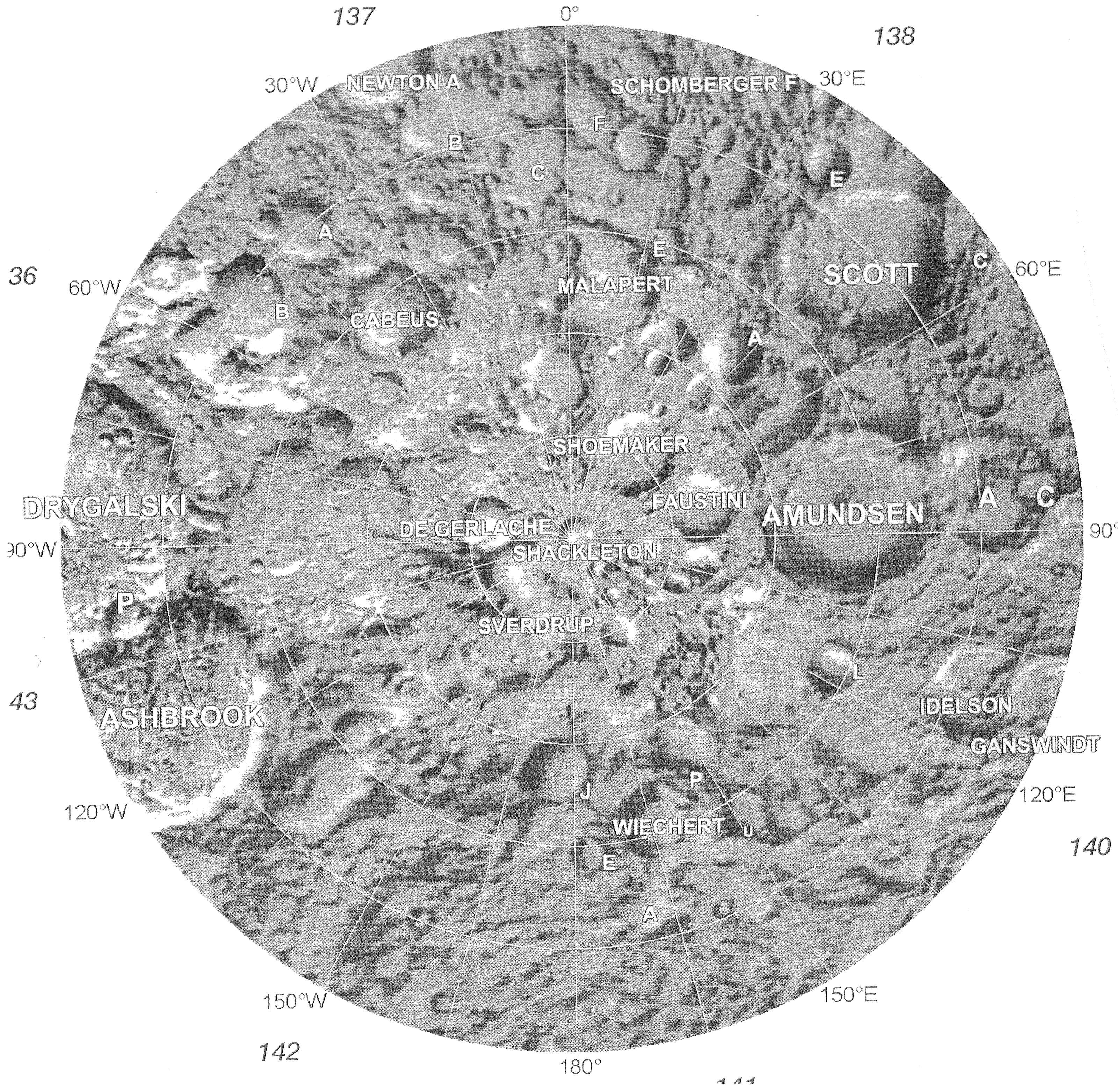
17. Grain size distribution curves for Apollo 16 samples and others (Mitchell et al., 1972). Ordinate shows percent finer by weight.

To Earth

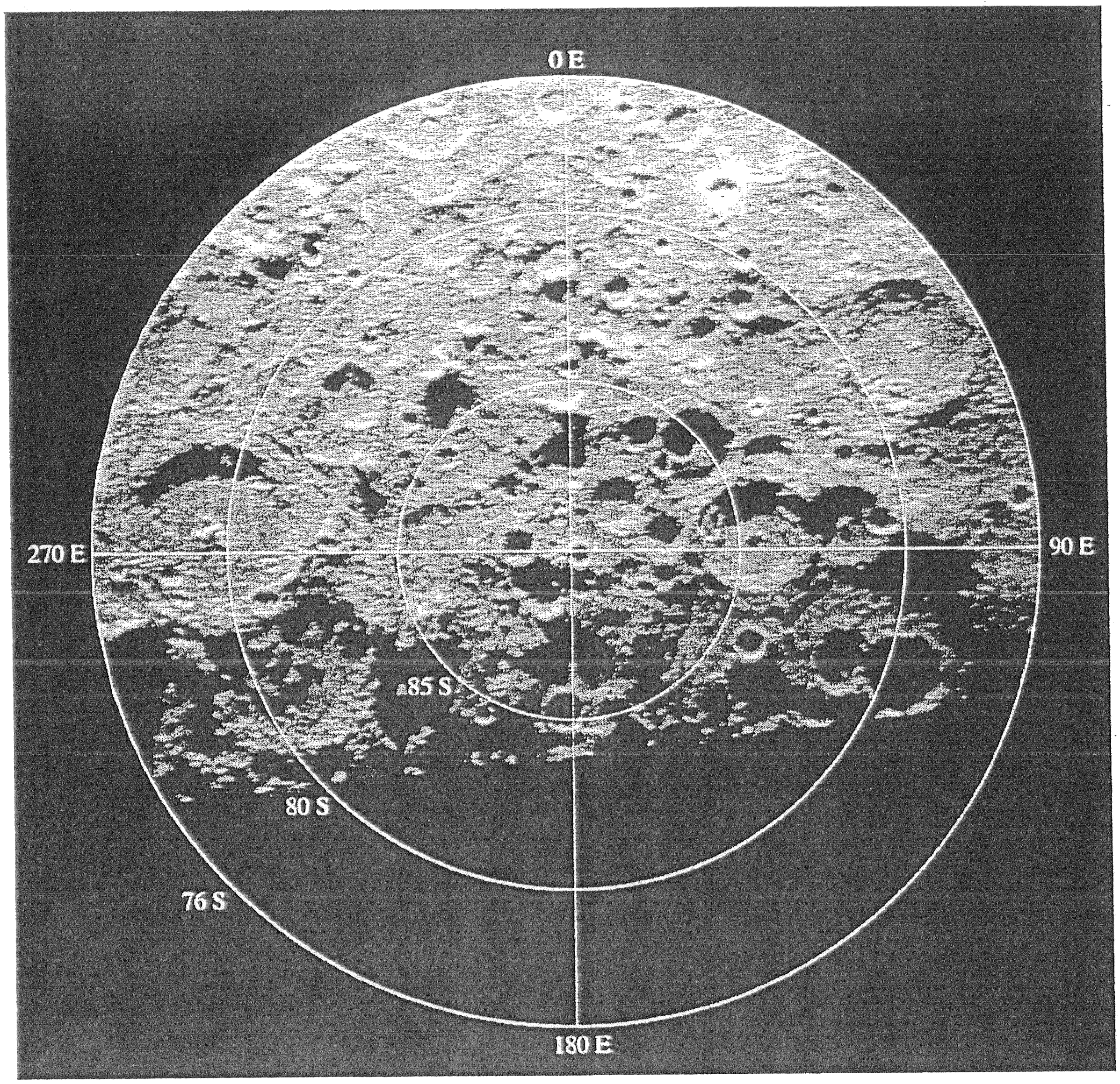


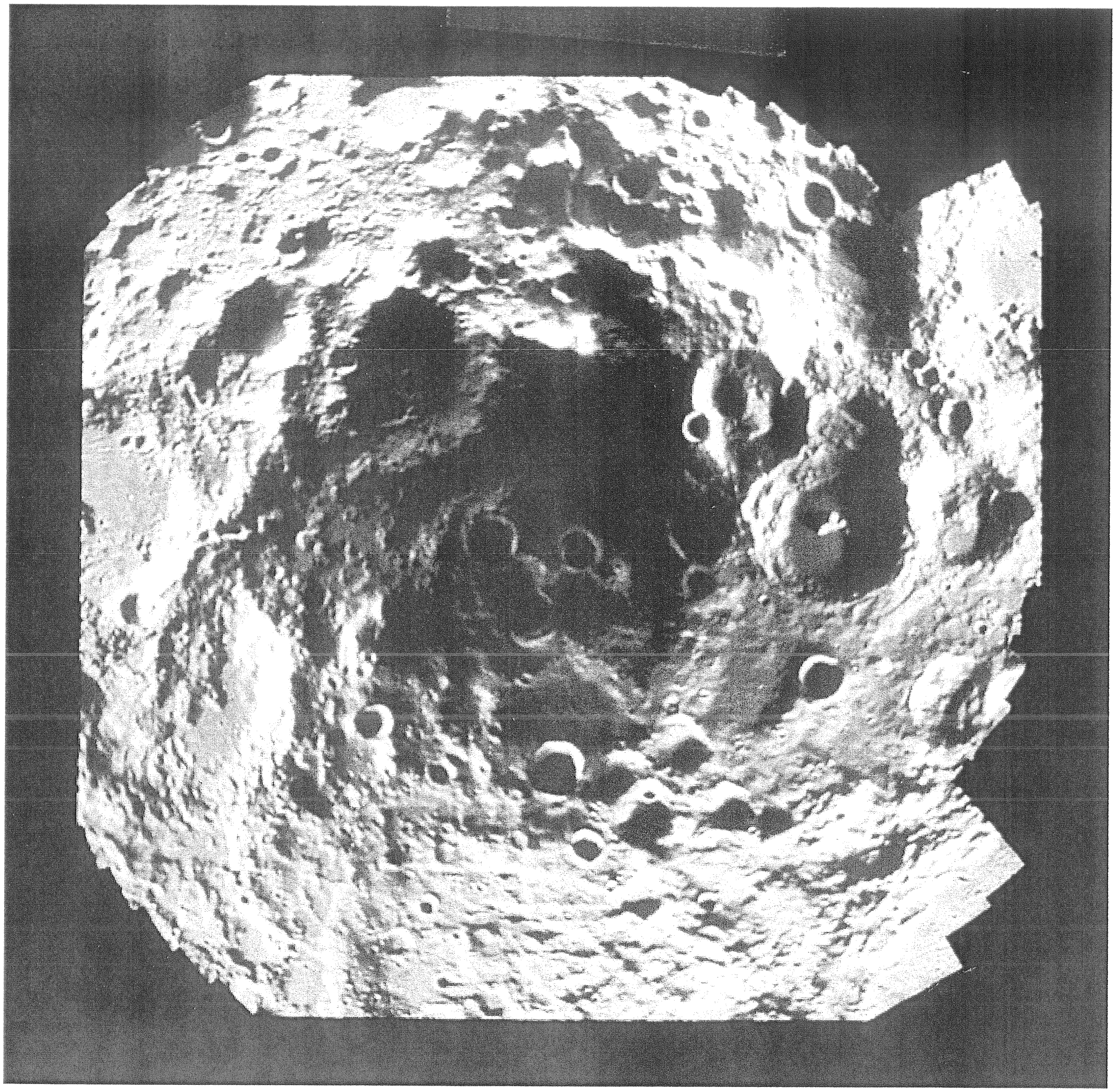
Clementine Mosaic


0°
30°W
30°E
60°W
60°E
90°W
90°E
120°W
120°E
150°W
150°E


137
0°
138
30°W
NEWTON A
SCHOMBERGER F
30°E
F
B
C
E
A
36
60°W
B
CABEUS
E
MALAPERT
SCOTT
C
60°E
A
SHOEMAKER
DRYGALSKI
FAUSTINI
AMUNDSEN
A
C
DE GERLACHE
SHACKLETON
90°W
90°
P
SVERDRUP
L
43
ASHBROOK
IDELSON
GANSWINDT
P
J
120°W
120°E
WIECHERT
U
E
140
A
150°W
150°E
142
180°

3


0 E
270 E
90 E
85 S
80 S
76 S
180 E



29. South Pole Mosaic

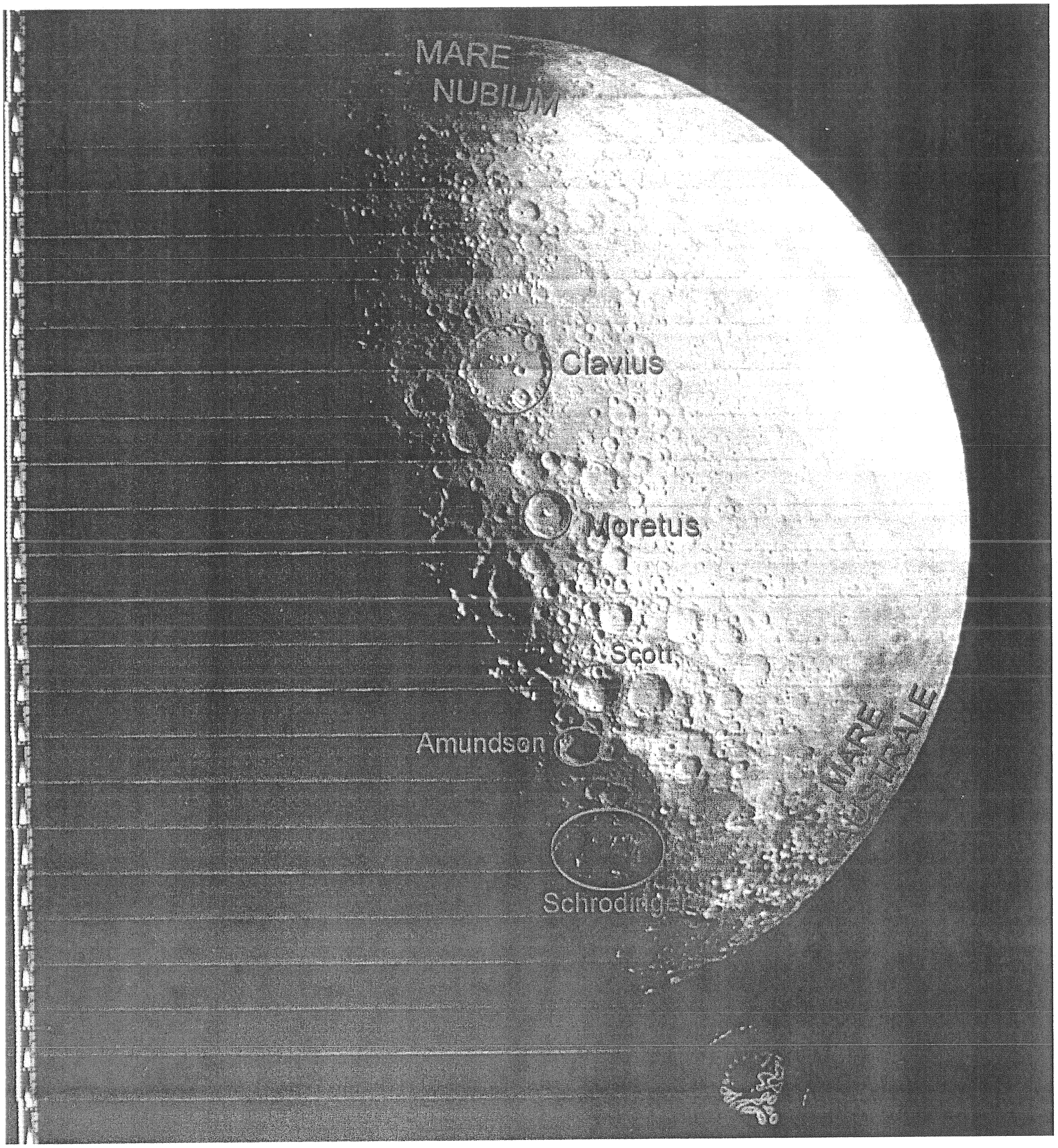
Mosaic of about 650 *Clementine* images of the south pole of the Moon, from 80°S to the pole (center). The nearside of the Moon is the top half of the image; the bottom half is the farside. The dark region near the pole indicates an old depression, inside the rim crest of the South Pole-Aitken Basin (slide #25). Large parts of this area (about 15,000 km^2) are permanently shadowed, and bistatic radar results from *Clementine* indicate that they could contain deposits of water ice.

5. South pole mosaic, 650 images, second month of coverage.

5

IV-118-M

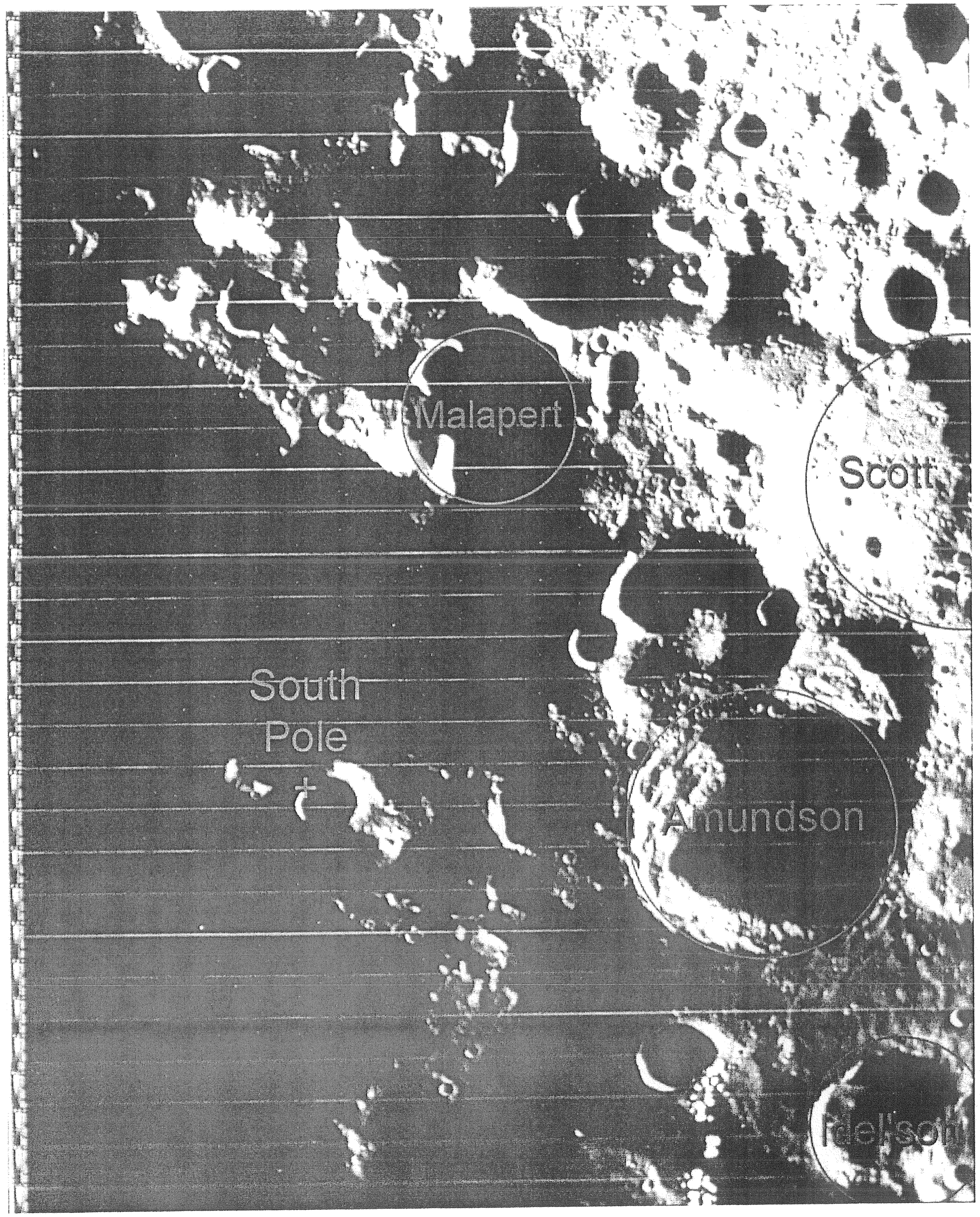
Netscape Search Lunar Orbiter photos Go Return to Results | Remove Frame



6

~~F26~~ -H1
IV - ~~F22~~
118-H1

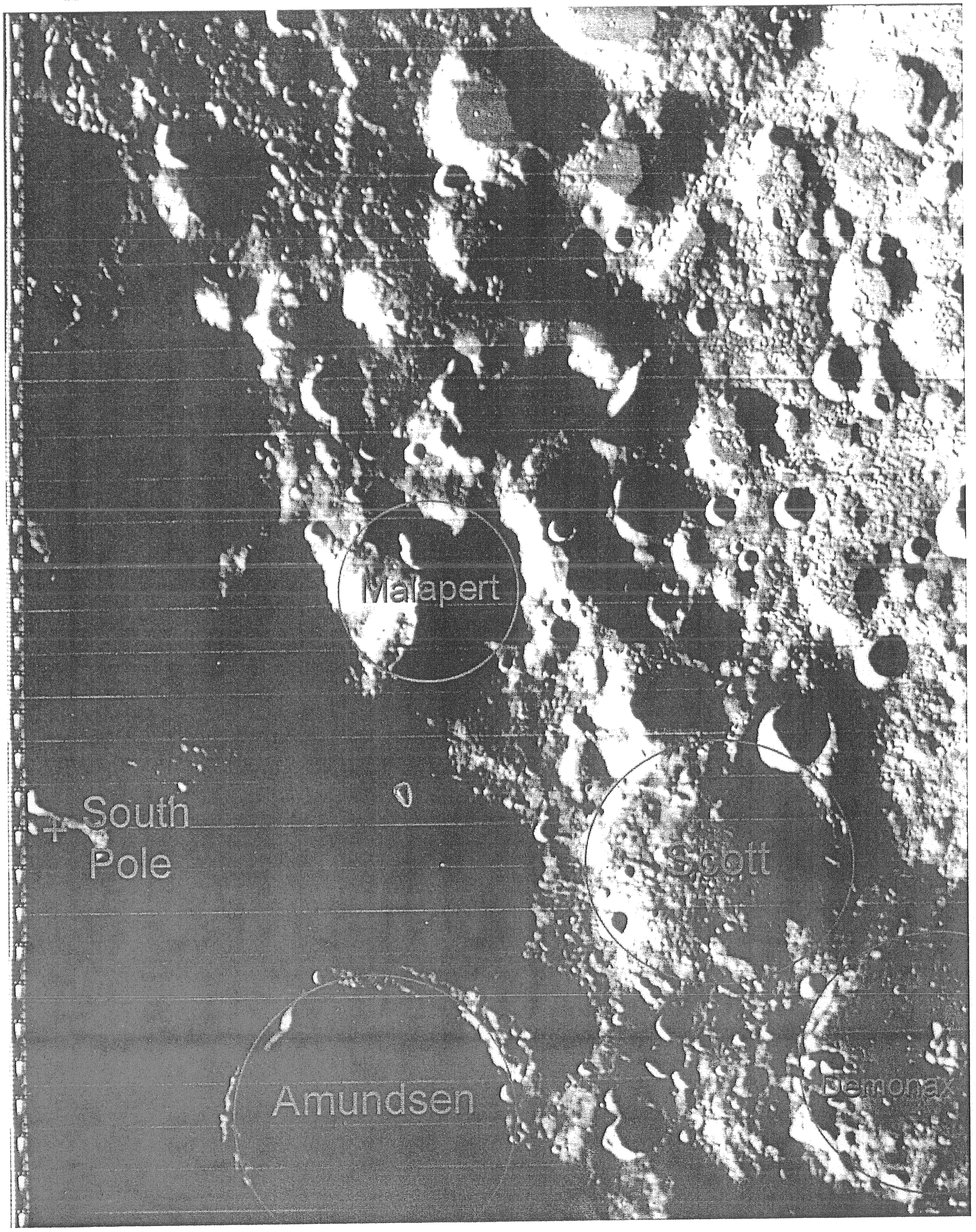
Netscape Search Lunar Orbiter photos Go Return to Results |



7

H-154-41

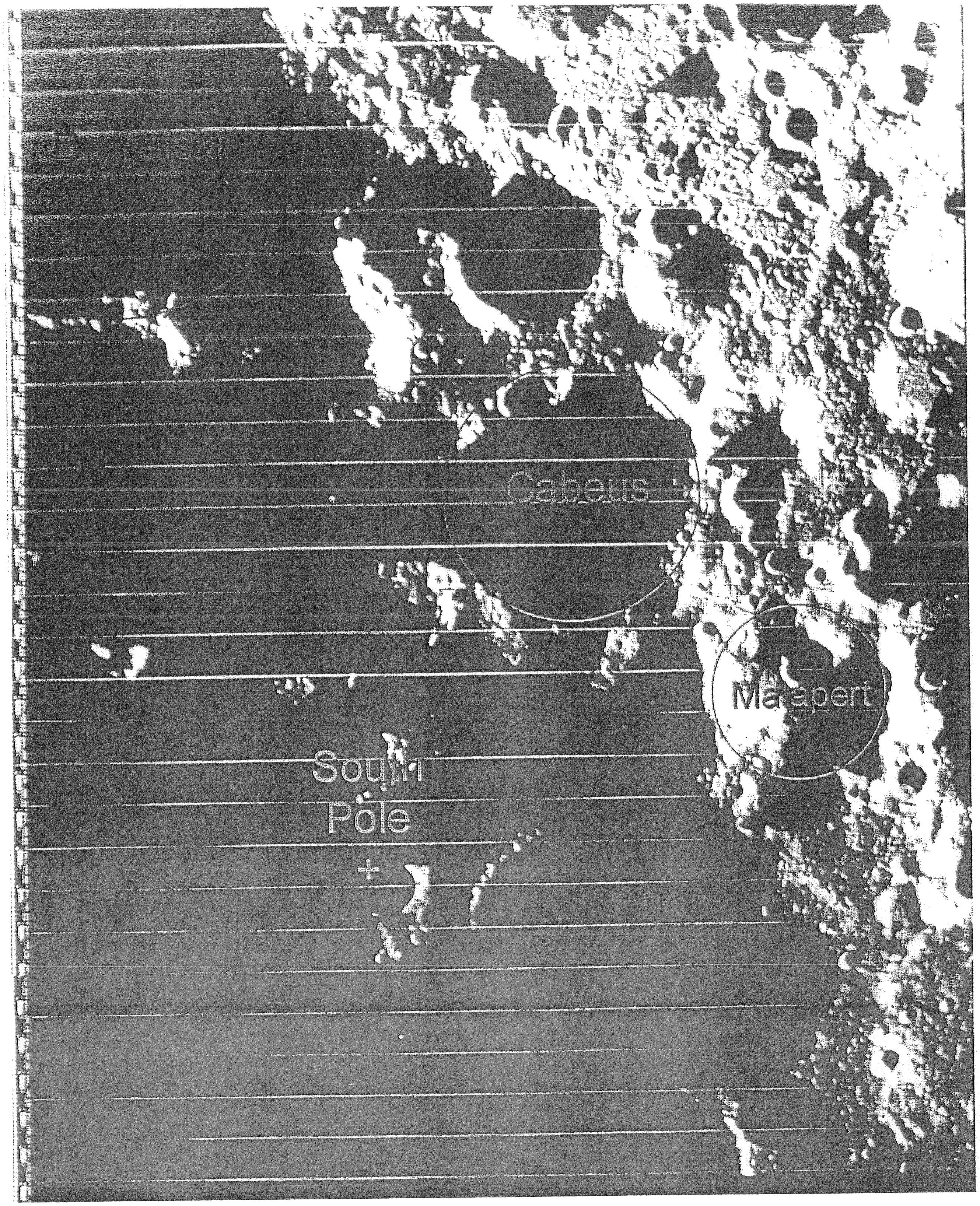
Netscape Search Lunar Orbiter photos Go Return to Results |



8

H-166-41

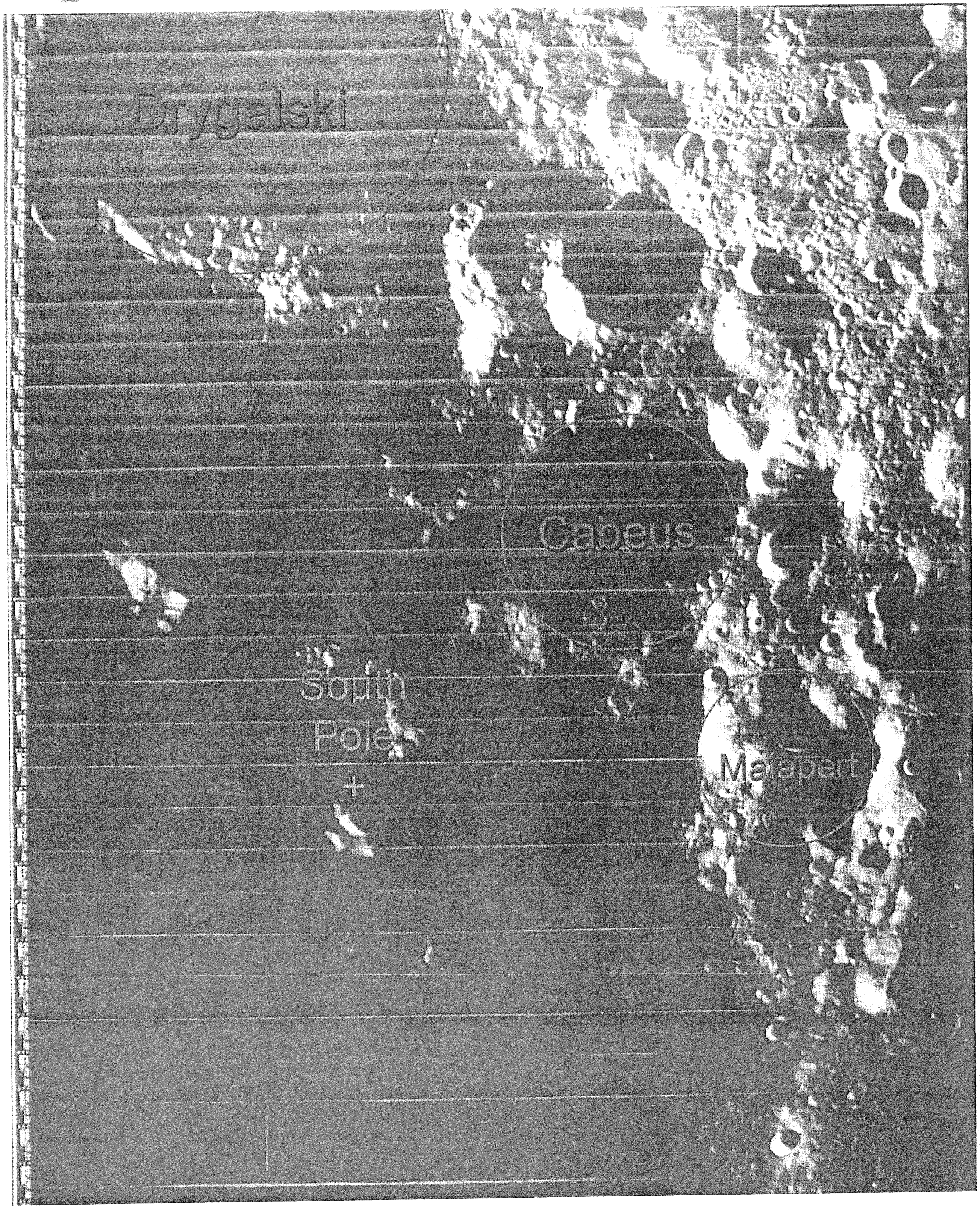
Netscape Search Lunar Orbiter photos Go Return to Results |



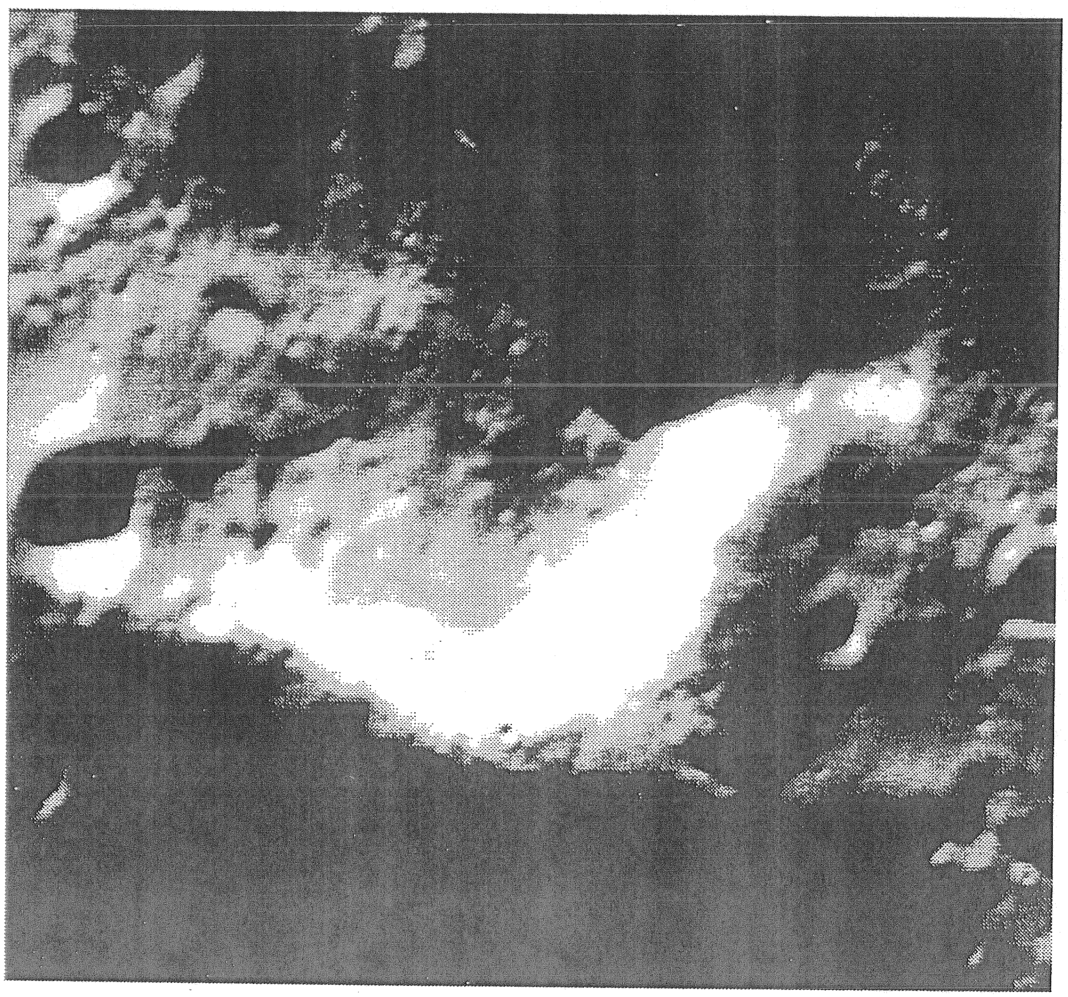
9

11-179-H1

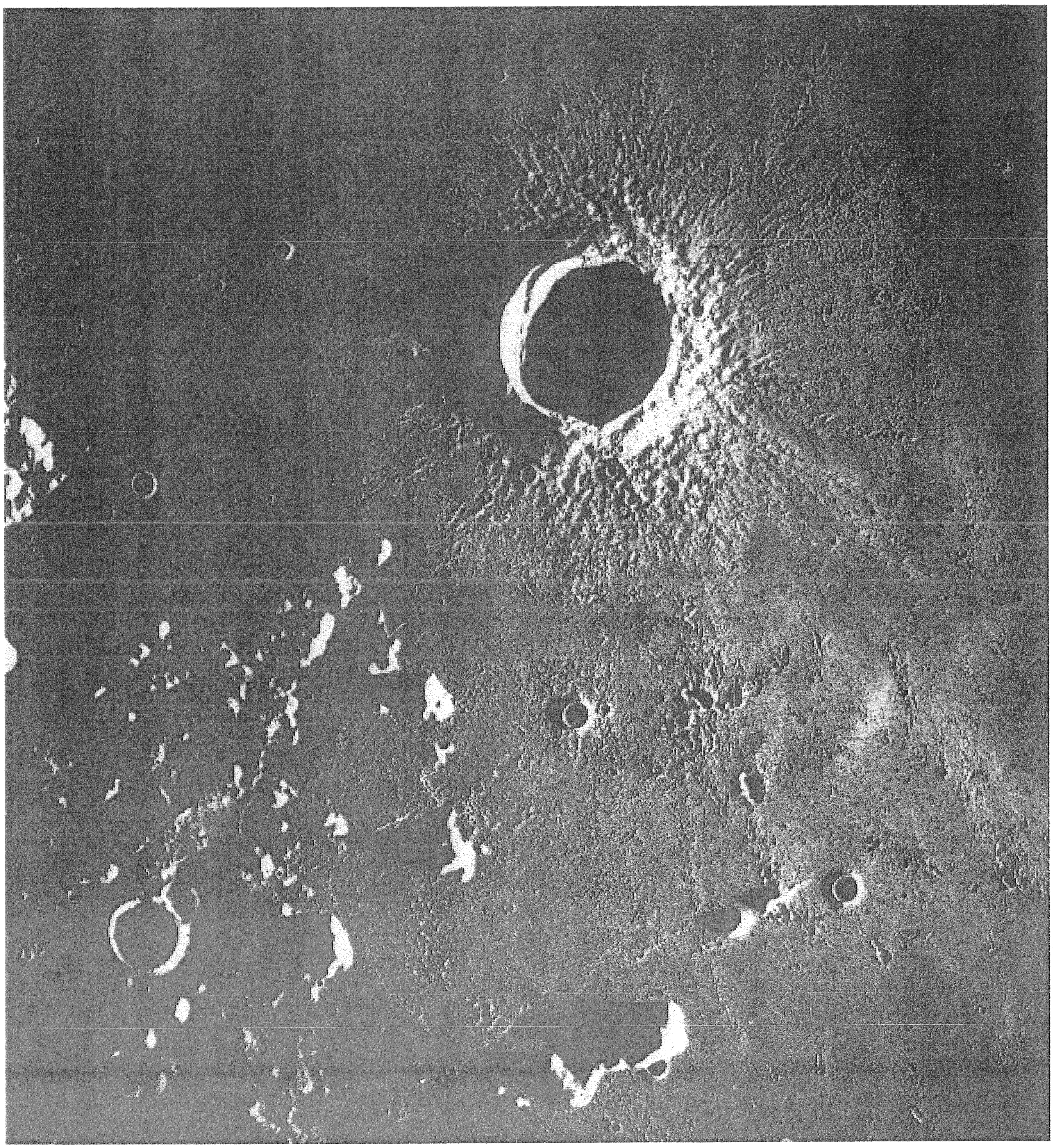
Netscape Search Lunar Orbiter photos Go Return to Results |



(10)

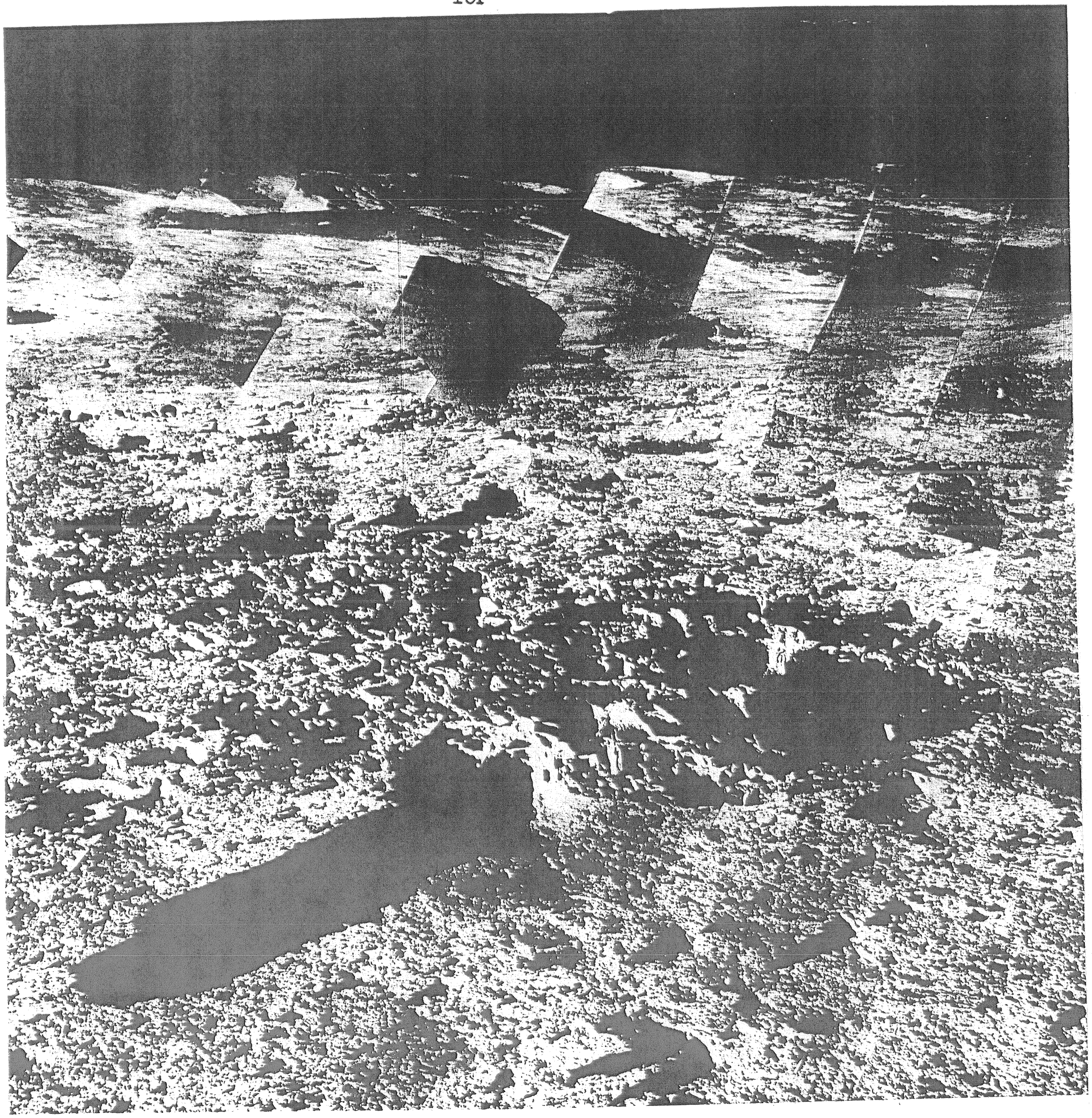


Netscape Search Apollo orbital photograph Go Return to Results |



(12)

TOP



13

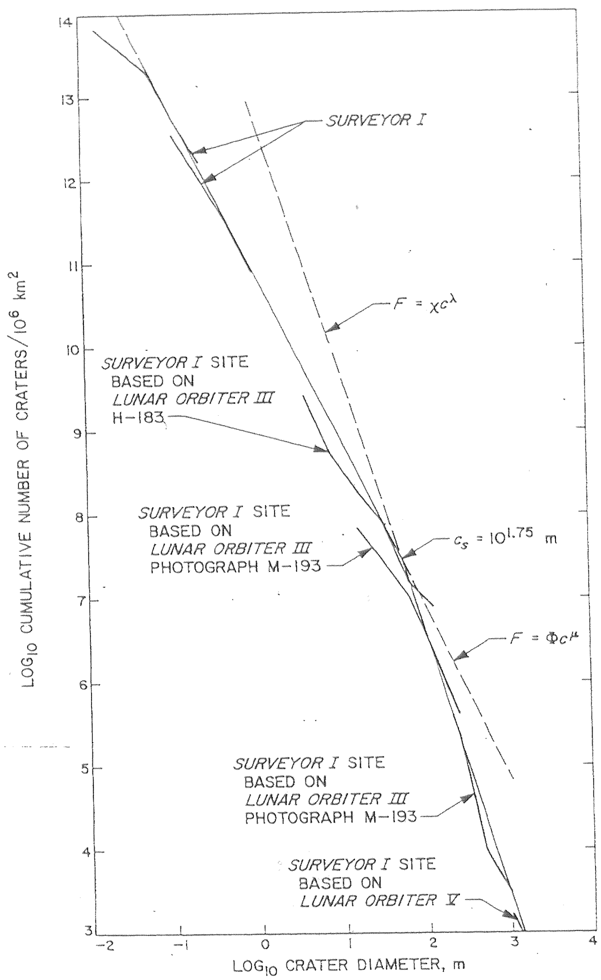


FIGURE 3-39.—Cumulative size-frequency distribution of small craters on the lunar surface in the vicinity of Surveyor I, determined from Surveyor I pictures and Lunar Orbiter III and V photographs.

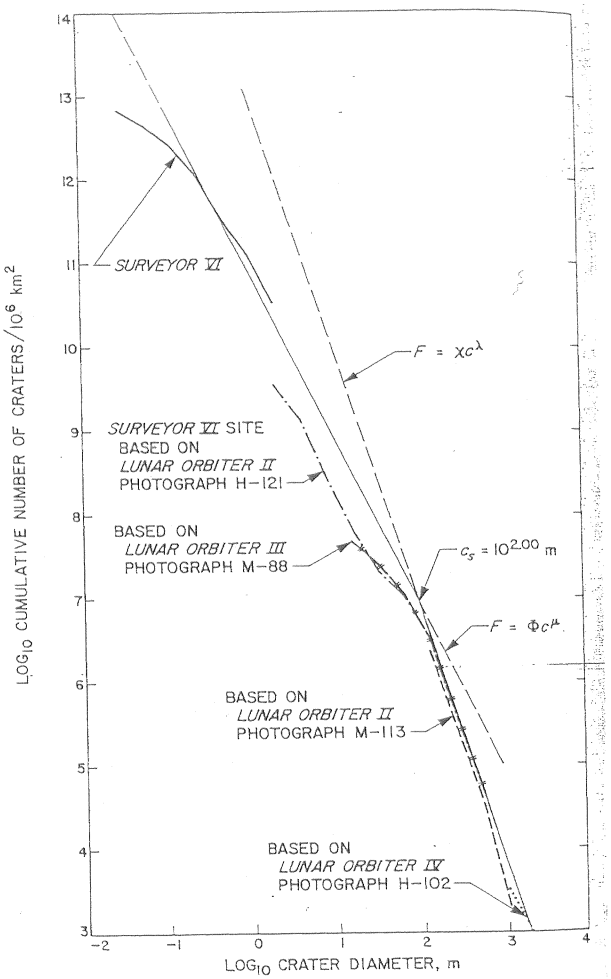


FIGURE 3-40.—Cumulative size-frequency distribution of small craters on the lunar surface in the vicinity of Surveyor VI, determined from Surveyor VI pictures and photographs from Lunar Orbiter II, III, and IV.

Fig. 14 Small crater populations, Surveyor I and VI sites. (Morris and Shoemaker, 1969).

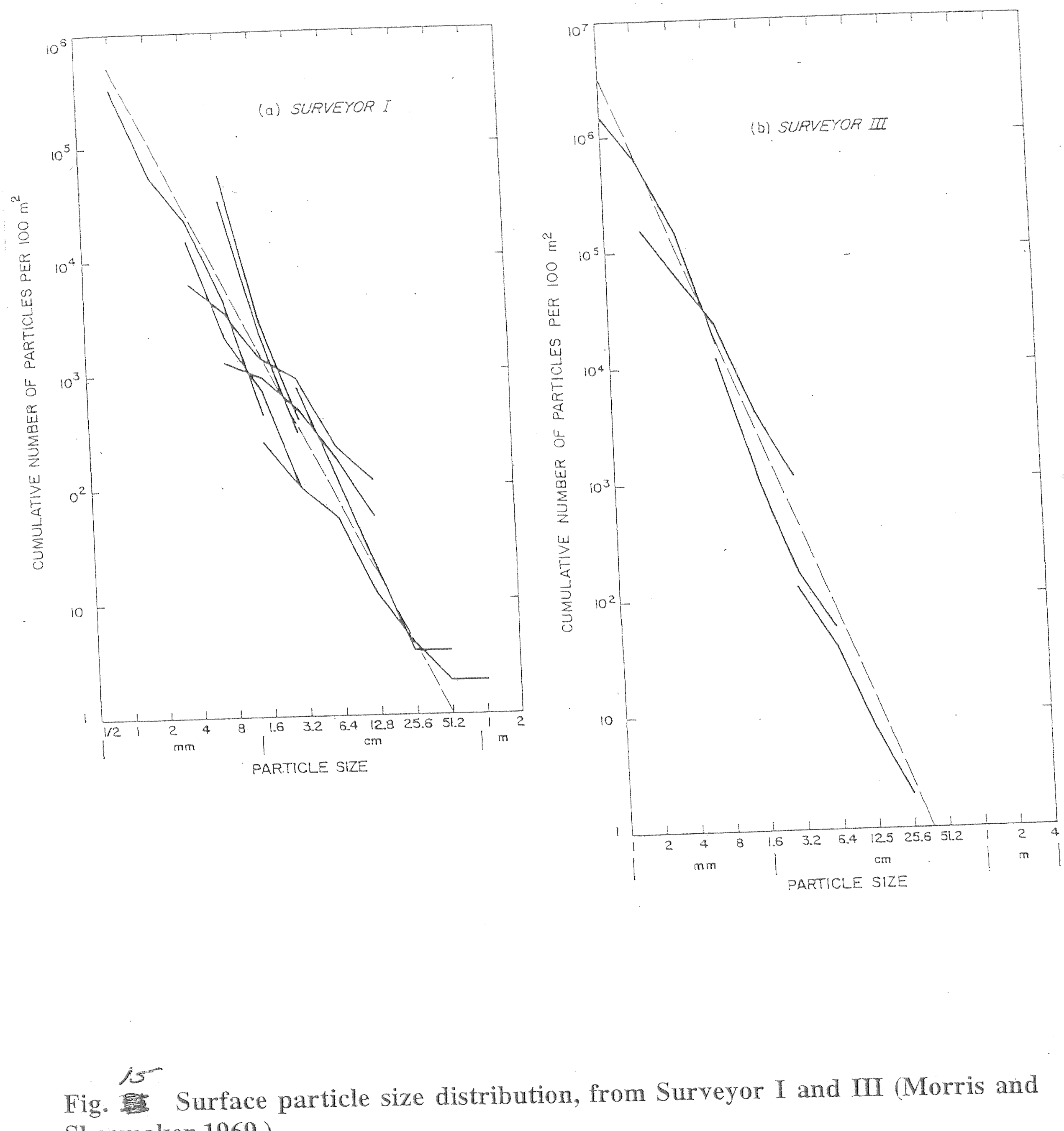


Fig. 15 Surface particle size distribution, from Surveyor I and III (Morris and Shoemaker,1969.)

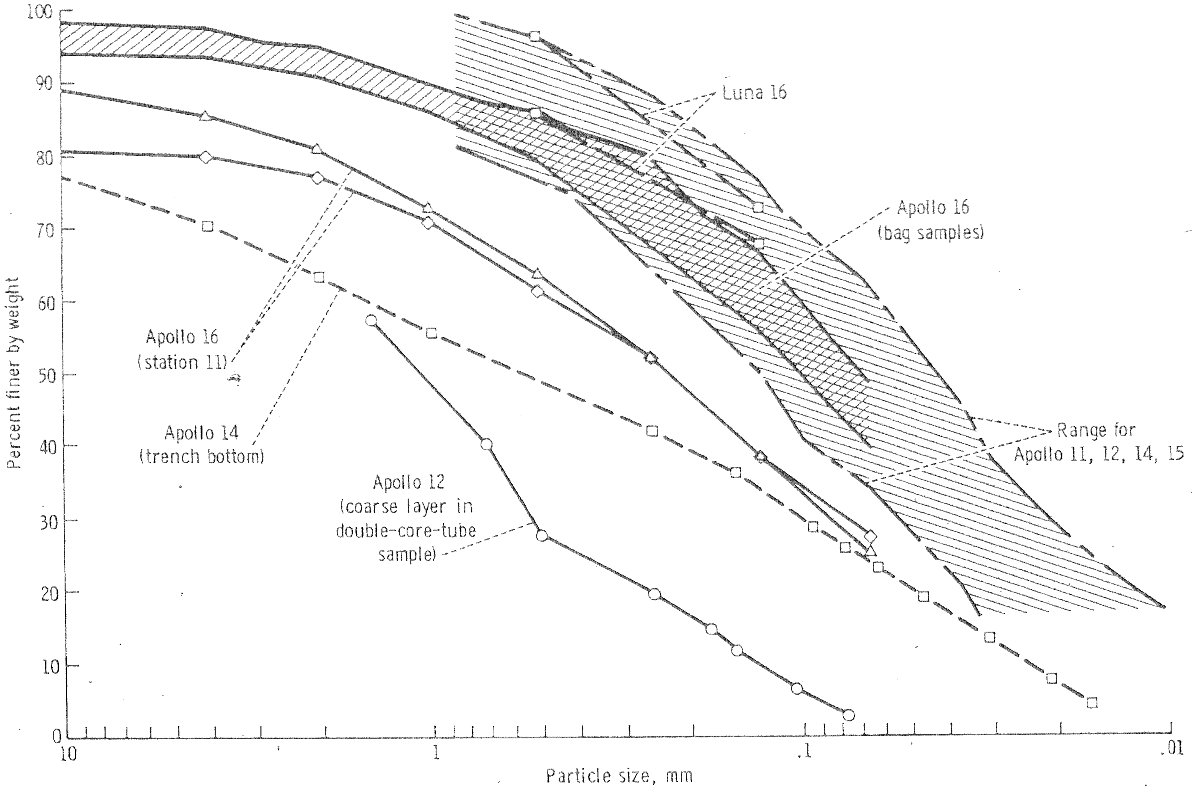


FIGURE ~~35~~ 17.—Grain-size-distribution curves for several Apollo 16 samples compared with composite distribution for samples from Apollo 11, 12, 14, and 15 missions and from two Luna 16 samples.

17

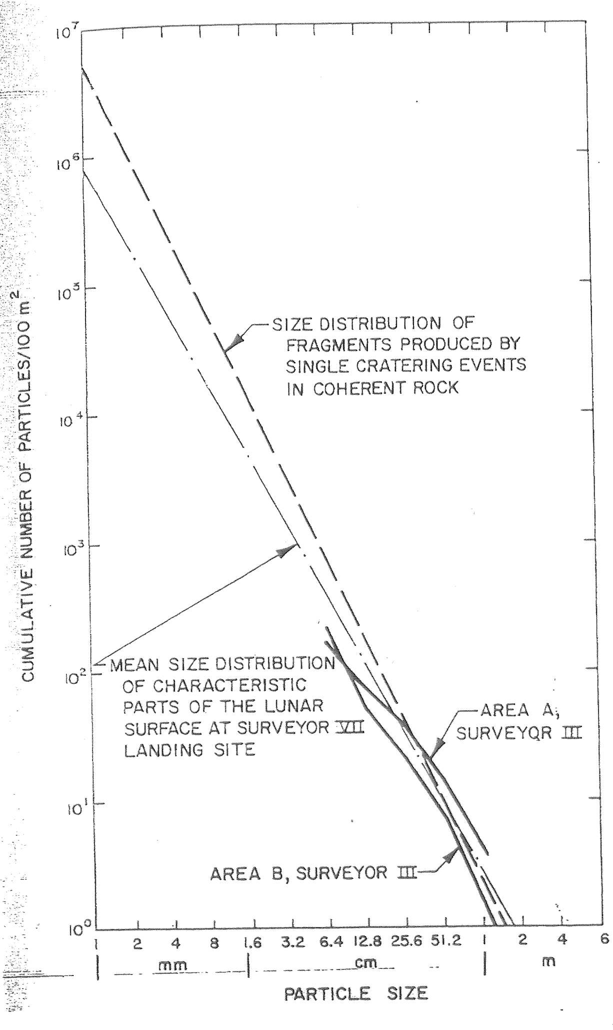


FIGURE ~~30~~ 16. — Cumulative size-frequency distribution of fragments on the lunar surface near Surveyor VII compared with size distribution of fragments produced by cratering events in coherent rocks. Curves labeled area *A* and area *B* are the size-frequency distributions of fragments in strewn fields of blocks around two craters near Surveyor III.

16